Effects of Nano-Silica on Mechanical Properties of Mortars

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Abstract

Nanotechnology is a new method; in addition it is a novel scale in the technologies and a modern approach in all fields which makes the human able to improve the structure of materials. Nano particles properties can affect in new technologies and consider as a big revolution in science.

Using nano-silica can improve the durability of concrete, so decrease the amount of cement for construction repair. As a consequence of this, environmental pollutions such as production of greenhouse (CO_2) decrease and the sustain development can be grown. Therefore, using nano-SiO_2 as a nano-scale additive in concrete is under further inspection by researchers.

In this paper different colloidal based solutions of nano-silica were used in preparation of mortar and their effects were studied on mechanical properties of mortar. The results showed superiority of specimens included nano-silica in improving of its compressive strength and capillary water absorption, and thus the mechanical properties and durability are improved compare to the control specimens.

Keywords: *Concrete; Nano-SiO_2; Compressive strength; Capillary water absorption.*

1 Introduction

Nano-particles have been gaining increasing attention and been applied in many fields to fabricate new materials with novelty function due to their unique physical and chemical properties (Ji, 2005). Nanotechnology is a new method, in addition it is a novel scale in the technologies and a modern approach in all fields which makes the human able to improve the structure of materials. Recently, nano technology has attracted considerable scientific interest due to the new potential uses of particles in nanometer (10^{-9} m) scale. The nano scale-size of particles can result in dramatically improved properties from conventional grain-size materials of the same chemical composition. There are few reports on mixing nano-particles in cement-based building materials (Jo et al., 2007). Nano-particles of SiO_2 (nS) can fill the spaces between particles of C–S–H gel, acting as a nano-filler. Furthermore, by the pozzolanic reaction with calcium hydroxide, the amount of C–S–H increases (Senff et al., 2009). Thus, the size and amount of calcium hydroxide crystals are significantly decreased (Ye et al., 2003). Nano-SiO_2 can behave as a nucleus to tightly bond with cement hydrates. The stable gel structures can be formed and the mechanical properties of hardened cement paste can be improved when a smaller amount of nano-SiO_2 is added (Ye, 2001). Higher densification of the matrix improves the strength and durability of the material when nano-silica used in cement mortar. For constant w/c ratio and cement content, increasing nano-silica from 1 to 2 percent of cement weight improved the infiltration resistance (Ji et al., 2009). It has been found that effectiveness

of the nano-SiO_2 in increasing strength increased with the increase on nano-SiO_2 volume fraction (Li et al., 2004).

In this paper, compressive strength and capillary water absorption of control mortar and two other mortars with different colloidal based solution of nano-Sio_2 are compared. Three specimens have fixed value w/b and slump flow amount. For debate of results, Zetasizer Nano and XRF tests in nano-silica solutions were inspected. The Zetasizer Nano range of instruments provides the ability to measure three characteristics of particles or molecules in a liquid medium. These three fundamental parameters are Particle size, Zeta potential and Molecular weight.

2 Experimental Program

2.1 Materials

The materials used in this study were ASTM Type I Portland cement, Silica amorphous colloidal based solutions with a solid content of 12.5%, 15%. The chemical constituent of these materials are shown in Table 1. The physical characteristics of types of nano-silica solutions are indicated in Table 2.

Table 1. Chemical composition of cement and two types of nano-silica solutions

Components	SiO_2	MgO	CaO	SO_3	Fe_2O_3	Al_2O_3	Na_2O	K_2O
Cement	19.9	2.07	64.1	4.09	4.1	3.83	<10ppm	0.79
Nano-SiO_2 (type 1)	63.9	0.15	0.087	0.39	0.038	0.15	17.3	4.3
Nano-SiO_2 (type 2)	91.5	0.085	0.065	0.26	0.021	0.085	0.97	0.013

Components	Cl_2	TiO_2	P_2O_5	MnO	LOI	C_2S	C_3S	C_3A	C_4AF
Cement	0.008	0.47	0.064	0.23	0.04	6.92	66.45	3.21	12.47
Nano-silica (type 1)	0.18	0.047	0.019	0.009	13.27	-	-	-	-
Nano-silica (type 2)	0.045	0.04	0.008	0.003	6.79	-	-	-	-

Table 2. Physical characteristics of two types of nano-silica solutions

Characteristics	Phase	Color	PH	Density (gr/cm^3)	Viscosity (cps)	Solid particles (Percent)
Nano-silica (type 1)	liquid	transparent	13	1.05-1.4	<10	12.5
Nano-silica (type 2)	liquid	transparent	10	1.1	<10	15

Aggregate is standard packing sand that produced in Iran and equivalent to DIN EN 196-1. The maximum size of sand particle is between 2-2.5 mm. Physical characteristics of sand are introduced in Table3.

Table 3. Physical characteristics of sand

Characteristics	water absorption(%)	SSD Density(gr/cm^3)	Fine modules
Sand	0.1	2.62	2.67

Very fine size and high specific surface of nano particle decrease the mortar workability. As a result a third generation of superplasticizer (SP) based on the ether carbocsilic (GELENIUM-110P) was used throughout this investigation.

2.2 Mix Proportion

Three mix proportions of mortars are presented in Table 4. Mortars which produced by type 1, type 2 of nano-silica solution are presented in NS-1 and NS-2 respectively. The percentage of used nano-silica in NS-1 and NS-2 is 5% by weight of cement. Mortar mix proportions were selected according to ASTM-C109 with water/binder ratio (w/b) of 0.485 and aggregate/cement ratio of 2.75. The amount of superplasticizer was adjusted in NS-1 and NS-2 mortars to achieve similar slump flow as control mortar.

Table 4. Mix proportions of specimens (kg/m^3)

mixture no.	Cement (kg)	Water (kg)	Sand (kg)	w/b	nano-SiO (kg)	SP (kg)	Slump flow(cm)
OPC	666	323	1831.5	0.485	-	-	13.8
NS-1	632.7	323	1831.5	0.485	33.3	8.65	14
NS-2	632.7	323	1831.5	0.485	33.3	27.9	14.1

2.3 Preparation of Mortars

After mixing nano-silica, water, superplasticizer in the mixer for few minutes, cement was poured to the mixture and the whole blend was mixed for 30 seconds. After adding the sand, mixing process was repeated for another 30 seconds with the higher speed of rotary mixer. After ceasing the mixing process for 2 minutes, blending the mixture was started again for 30 seconds.

The slump flow of achieved mortar was measured by flow table test according to ASTM C-230. For better comparison between mortars, the slump flow of NS-1and NS-2 should be equal to slump flow of OPC. The mortar was casted into 5 cm cubic molds. Compaction was carried out using a plastic tamper in 2 layers, each layer compacted by 32 blows. The molds were covered with the burlap and kept wet for 24 hours after casting. The specimens were removed from the molds and were allowed to cure in lime saturated water at 20 °C for 7 and 28 days.

3 Results and Discussion

3.1 Zetasizer Nano

The Zetasizer system determines the size by first measuring the Brownian motion of the particles in a sample using Dynamic Light Scattering (DLS) and then interpreting a size from this using established theories. When a particle moves (e.g. due to gravity), ions within the liquid layer surrounding the article (boundary) move with it, but any ions beyond the boundary do not travel with the particle. This boundary is called the surface of hydrodynamic shear or slipping plane. The potential that exists at this boundary is known as the zeta potential. The magnitude of the zeta potential gives an indication of the potential stability of the colloidal system. If all the particles in suspension have a large negative or positive zeta potential then they will tend to repel each other and there is no tendency to flocculate.

However, if the particles have low zeta potential values then there is no force to prevent the particles coming together and flocculating. The general dividing line between stable and unstable suspensions is generally taken at either +30mV or -30mV. Particles with zeta potentials more positive than +30mV or more negative than -30mV are normally considered stable (Zetasizer Nano Series User Manual, 2004).

The size of solid particles of different nano-silica solutions are shown in Figures 1 and 2.

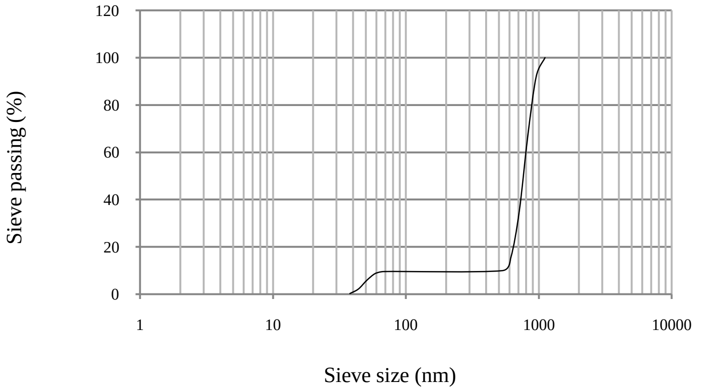

Figure 1. Size of solid particles of nano-silica solution (type 1)

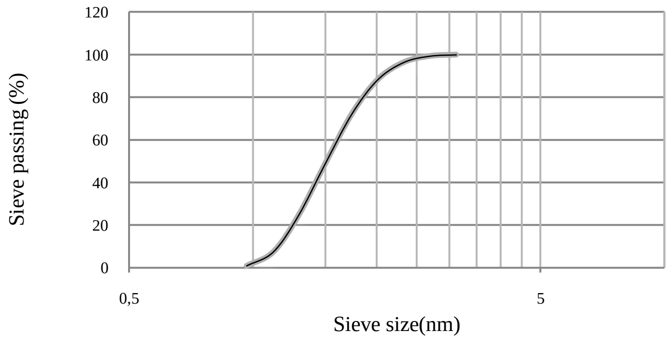

Figure 2. Size of solid particles of nano-silica solution (type 2)

As a result, type 1 of nano-silica solution has gap graded distribution with about 800 nm average size and type 2 of nano-silica solution has well graded distribution with about 1.5 nm average size. Zeta potential of colloidal particles in type 1 and type 2 of nano-silica solutions are -8.71 mV and -44 mV respectively. The better mechanical properties of NS-2 mortar can be attributed to finer solid particle of nano-SiO_2 solution which provides superior filler effects in concrete. It is also referred to colloidal instability of type 1 nano-sio_2 and colloidal stability of type 2 nano-SiO_2 particles that caused magnification of repelled forces between nano-SiO_2 solid particles in NS-2 mortar.

3.1 Compressive Strength

The compressive strength of mortars at the ages of 7days and 28 days are shown in Figure 3.

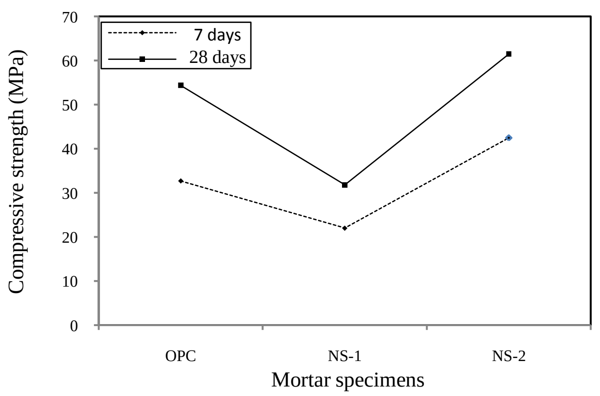

Figure 3. Compressive strength at the age of 7 and 28 days

Nano-SiO_2 particles can react with calcium hydroxide $Ca(OH)_2$ crystals, which are mostly formed in the interfacial transition zone (ITZ) between hardened cement paste and aggregates and produce secondary C–S–H gel. Thus, the size and amount of calcium hydroxide crystals are significantly reduced, and more C-S-H fills the voids in interfacial transition zone (ITZ) to improve the density of matrix (Ye et al., 2003). Nano-SiO_2 can behave as a nucleus to tightly bond with cement hydrates. The stable gel structures can be formed and the mechanical properties of hardened cement paste can be improved when nano-SiO2 is added (Ye, 2001). As a result, nano silica usually improves the compressive strength of mortar mixes. This can be clearly NS-2 specimens. Table 5 shows the compressive strength differences in normal mortar and mortars containing two types of nano-SiO_2.

Table 5. Compressive strength test results

Mixture Id	**Compressive strength at 7 days**		**Compressive strength at 28 days**	
	Target(MPa)	Improvement (%)	Target(MPa)	Improvement (%)
OPC	32.7	0	54.4	0
NS-1	22	-32.7	31.8	-41.5
NS-2	42.5	30	61.5	13

The nano-particles are more difficult to be dispersed uniformly in cement paste by increasing their content in the solution. The aggregation of nano-particles will form weak zones in cement paste. As a result, the enhanced extent of compressive strength of concrete decreases (Li et al., 2007).

Regarding the zeta potential test results for NS-1 specimen and unstable colloidal particles in solution, homogeneity of nano particles in mortar does not occur. Because of agglomeration of particles and creation of weak zone, compressive strength reduction is reduced.

3.3 Capillary Water Absorption

Amount of absorbed water can be related to void capillary spaces form and its arrangement. High quantity of capillary water absorption can be alluded to weakness of structural cement matrix, high permeability and destructive exposure of chloride diffusion.

Because of pores and capillaries in mortars empty from water, cured specimens were put in 50°C oven for 10 days. In purpose of water infiltration from bottom surface of specimen exclusively, lateral faces were covered by epoxy. The specimens placed vertically in container in contact with water and weighed at 3, 6, 24 and 72 hours old.

Capillary water absorption processes in mortar specimens at 7 and 28 days, are shown in Figures 4 and 5 respectively.

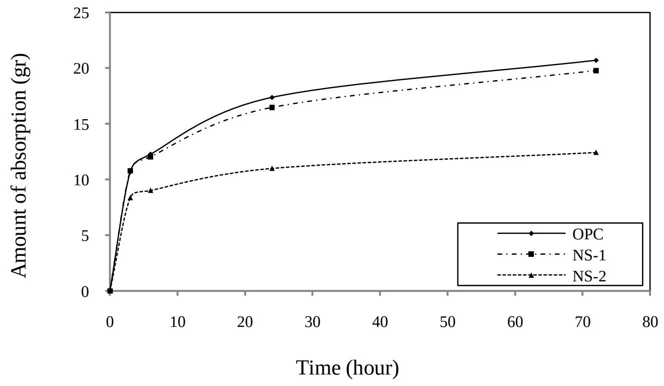

Figure 4. Capillary water absorption at 7 days

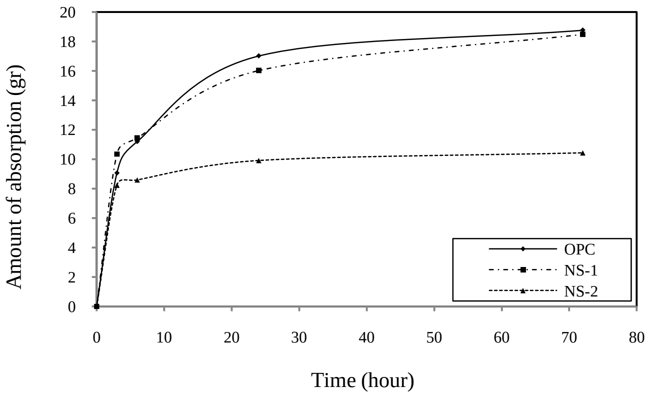

Figure 5. Capillary water absorption at 28 days

Capillary absorbed water can be described in following formula that indicated the rate of liquid superficial absorption via pored solid sample (Ghrichi et al., 2007).

$$s = \frac{W}{A.t^{0.5}} \tag{1}$$

W: absorbed water content in specimen at the end of experiment
A: section area of specimen
T: time (72 hours)
Density of water is 1 gr/cm^3 hence this unit declared in $\frac{gr}{cm^2hr^{0.5}}$ or $\frac{cm}{hr^{0.5}}$.

Capillary water absorption coefficient(s) are shown in Table 6.

Table 6. Assessment of capillary water absorption coefficient

Mixture no	**Capillary water absorption coefficient at 7 days**		**Capillary water absorption coefficient at 28 days**	
	Target (cm×1000/hr$^{0.5}$)	Reduction (%)	Target (cm×1000/hr$^{0.5}$)	Reduction (%)
OPC	97.5	0	88.4	0
NS-1	93.1	4.5	87.1	1.5
NS-2	58.6	40	49.2	44.3

From this graphs can be found that nano-silica mortars have less capillary water absorption to control mortar and maximum reduction in capillary water absorption is referred to NS-2 mortar. The rate of decrease capillary water absorption of NS-1 specimen is less than NS-2 one. This matter can be related to unstable colloidal particles in type 1 of nano-sio$_2$ solution and non-homogeneity of nano particles in mortar.

4 Conclusions

1) Addition of two different colloidal nano-silica based solutions to mortars decreased the compressive strength in type 1 of nano-silica specimen and increased it in type 2 of nano-silica specimen and improved capillary water absorption in both nano-silica specimens.
2) Decrease percent of capillary water absorption is more than increase percent of compressive strength in the mortar specimens.
3) This advantage of NS-1 specimen to NS-2 specimen can be followed as below:

- XRF test results have been shown that sio$_2$ content of type 2 of nano-silica solution can enhance the pozzolanic performance.

- Outcomes of zetasizer test in determination of particle sizes showed that type 2 of nano-sio2 solution has a better capability in filling of nano-scale pores.
- Also zetasizer test have indicated colloidal instability of type 1 of nano-sio_2 and colloidal stability of type 2 of nano-sio_2 particles that caused reduction of repelled forces and increase of flocculated colony between nano-sio_2 solid particles in NS-1 mortar.

References

Ghrichi, M., Kenai, S. and Said-Mansour, M. (2007). Mechanical Properties and Durability of Mortar and Concrete Containing Natural Pozzolana and Limestone Blended. *Cement and Concrete Composites*, vol. 29, pp. 542–549.

Ji, T. (2005). Perliminary study on the water premeabiity and microstructure of concrete incoroporating nano-sio_2. *Cement and Concrete Research*, vol. 35, pp. 1943–1947.

Jo, B. W., Kim, C. H., Tae, G. H. and Park, J. B. (2007). Characteristics of cement mortar with nano-SiO2 particles. *Construction and Building Materials*, vol. 21, pp. 1351–1355.

Li, H., Xiano, H.G., Yuan, J. and Ou, J. (2004). Microstructure of cement mortar with nano-particles. *Cement and Concrete Composites,* vol. 35, pp. 185–189.

Li, H., Zhang, M. H. and Ou, J. P. (2007). Flexural fatigue performance of concrete containing nano-particles for pavement. *International Journal of Fatigue 29*, pp. 1292–1301.

Malvern Instruments Ltd., Zetasizer Nano Series User Manual. (2004). Man0317, Issue 1.1.

Senff, L., Labrincha J. A., Ferreira, V. M., Hotza, D. and Repette, W. L. (2009). Effect of nano-silica on rheology and fresh properties of cement pastes and mortars. *construction and Building Materials*, vol. 23, pp. 2487-2491.

Ye, Q. (2001). Study and development of nanocomposite cement-based material. *Gypsum and Cement for Building,* vol. 11, pp. 4–6.

Ye, Q., Zhang, Z.N., Chen, R.S. and Ma, C.C. (2003). Interaction of nano-SiO2 with calcium hydroxide crystals at interface between hardened cement paste and aggregate. *Journal of the Chinese Ceramic Society*, vol. 31, pp. 517–522.

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